DUNLAP

Permeability of Concrete

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PERMEABILITY OF CONCRETE

BY

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I recommend that the thesis prepared under my supervision by ROBERT MURATT DUNLAP entitled Permeability of Concrete be approved as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

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PERMEABILITY OF CONCRETE

CONTENTS

I. INTRODUCTION

The increasing use of concrete for tanks and reservoirs, and in various kinds of conduit and subway work has made it necessary that the concrete used for this purpose should be water-tight. Due to this fact a great many more or less successful methods of water-proofing have been brought into practice. A study of water-proofing methods is being made by many engineers, in order to determine the one most efficient for making concrete impermeable. The purpose in this thesis is, first, to bring together the most important facts concerning this subject as they have been determined by the experiments of others, and second, to give a description of tests performed by the writer for the purpose of determining the effect of water-proofing ingredients upon the permeability of concrete.

II. GENERAL DISCUSSION

Tightness against penetration by water is chiefly important in two classes of structures, those whose purpose it is to inclose a space which must be kept dry, and those which are used to contain water. The first class includes such structures as subways for pipes and wires, and underground railways; in the second class are included tanks, aqueducts, sewers etc. The degree of impermeability that is necessary depends upon the use to which the structure is to be put. In underground railways it is not only important that water be excluded, but also that all dampness be prevented; while, on the other hand, in aqueducts it is not necessary to obtain any more thightness than is necessary to make sure that the leakage is not a considerable drain on the suply of water which passes through the aqueduct. The problem of the engineer is to secure that degree of impermeability which is required, in the most practical and most economical way.

Some of the earliest experiments to test the permeability of concrete were made by Mr. R. Feret of the Boulogue Laboratory of Ponts et Chaussees, in France. Mr. Feret made elaborate tests extending over a period of five years, after which he deduced the following conclusions:-

(I) "That in all concretes of granulometric composition, the most permeable are those which contain the least quantity of cement."

(2) "The minimum permeability is found in mortars where

the proportion of medium size grains is small, and the coarse and fine grains are about equal to each other."

(3) The permeability of concrete submitted to a continuous filtration diminishes very rapidly."

The above conclusions have since been verified by many other experimenters. In a number of experiments it has been noticed that the water in passing through the concrete absorbed lime and deposited it upon the surface of the concrete, thus forming a perfect seal against further percolation. This led to advocating the addition of slaked lime to the concrete mixture. The effect of adding slaked lime to the mixture is shown by the conclusions deduced from tests by Sanford E. Thompson, as follows:-

"(I) Slaked lime increases the impermeability of concrete.

(2) Effective proportions of hydrated lime for impermeability of concrete are;

Portland Cement	Sand	Stone	Hyd. Lime in Per Cent Of Cement
I	2	4	8
I	2.5	4.5	I2
I	3	5	I6

(3) Coarser sand would require a larger per cent of lime"

The increasing use of concrete for structures which must be water-proof has led to a search for some economical method for obtaining impermeability. In the above discussion

there is indicated two general methods of making concrete impermeable, and in addition to these there are two others. The four methods are;

I. the use of some coating which is distinct and separate from the concrete, such as bituminous compounds, with or without the addition of paper or felt.

2. the application of washes or paints to the hardened surface of the concrete.

3. scientific grading of the sizes of the materials of which the concrete is made.

4. the use of compounds which are added to the usual materials when they are mixed, thus forming an integral part of the concrete.

The first of these methods is very common; however, it does not consist in making the concrete itself water-tight, but is the using of another separate material which is impermeable . The impervious coat is usually some form of asphalt, used sometimes alone and sometimes in connection with tarred paper or felt. The results of this method are very satisfactory, as is shown by the entire absence of dampness in the railway tunnels in New York , which are water-proofed by six layers of asphalt alternating with the same number of layers of tarred felt.

The second method is also much used, especially for cisterns and for the walls and floors of basements. A number of paint compounds are now on the market. These prove very satisfactory if renewed from time to time.

The most efficient of the washes is a mixture of solutions of soap and alum, which is used very extensively. The use of paints and washes is not, properly speaking, a method of making water-proof concrete but rather of making concrete structures water-proof by covering them with an impermeable coating.

The third method, grading the materials, has been used to some extent, and experiments show that concrete can be made water tight by careful use of this method. A. L. True and J. B. McIntyre as a result of their experiments, described in the "Engineering News" January 26, 1902, conclude that, at a pressure of eighty pounds per square inch, a concrete of 1:2:4 or richer mixture is practically impermeable under any conditions ordinarily found in practice. Tanks, aqueducts and similar structures have been water-proofed in this manner, and the results are very satisfactory. This method of water-proofing seems not to have been used to advantage as yet in structures that must be absolutely dry. In practice less attention has been paid to developing this method than has been given to developing that of using some water-proofing ingedient. This is the case probably because the latter method is quicker, easier, and in most cases cheaper. However, it is the opinion of the writer that more attention should be given to securing impermeability by the proper grading of the sizes of the materials.

The fourth method, adding some ingredient to the concrete when it is mixed, is receiving a great deal of attention and there is a large number of proprietary water-proofing com-

pounds now on the market. The fact that some of these give excellent results and others give very poor ones makes it desirable to test any untried compound severely before using it in any important work. Proprietary compounds are put on the market in two ways, namely, as a compound which the user mixes with ordinary cement, and as water-proof cement which is prepared by the manufacturer. One of the most common ingredients used in concrete for making it water-proof is a combination in some form, of soap and alum. The experiments of Professor I. O. Baker show that this ingredient decreases the permeability of concrete as much as 50 to 70% . For the results of these experiments the reader is referred to the Technograph of the University of Illinois 1908-1909. Experiments performed by M. K. Jordan and described in his thesis "Effect of Soap and Alum upon the Permeability of Concrete", 1909, show similar results as those above. Professor Baker states in his article that the use of aluminum sulphate and soap proves more satisfactory than soap and alum, and is much cheaper. The results obtained by F. M. McCullough, of the University of Wisconsin, (see The Wisconsin Engineer, February, 1910,) and I. G. Ferguson of the University of Illinois,(see thesis " Effect of Water-Proofing Compounds upon the Permeability of Concrete", 1910,) in their tests of a number of commercial compounds upon the permeability of concrete show that the permeability of concrete is decreased by their use.

The results of the experiments mentioned in the preceding pages indicate that it is practicable to make concrete in-

permeable to any required degree by the use of one or more of the methods described. In conclusion a number of references relating to the permeability of concrete will be given.

I. Discussion "Impervious Concrete",in "Transactions of American Society of Civil Engineers", 1903.

2. "Concrete Plain and Reinforced", Taylor and Thompson.

3. "The Water-Proofing of the Foundation of the State Education Building at Albany,New York", Engineering Record Oct.16, 1909.

4. "Water-Proofing the New Ulm Concrete Reservoir at New Ulm, Minn", Engineering Record Dec. 17, 1910.

5. "Permeability Tests of Cement Concrete by Experiment Station of Iowa State College", Engineering Record Feb. 4, 1911.

6. "Water-Proofing with Water", Engineering Record Dec. 31, 1910.

7. "Tests of Soft Soap for Water-Proofing Concrete", Engineering Record Feb. 25, 1911.

8. "Water-Proofing a Sewer in Denver", Engineering Record Feb. 11, 1911.

III. DESCRIPTION OF TESTS

1. Materials

In these experiments Chicago A A portland cement, Wabash sand which passed a sieve having 0.2-in. openings, and Kankakee limestone which passed a 1/2 in. screen were the principal materials used in making the test pieces. The results of sieve analyses tests of these are shown in Tables 1, 2, and 3 and Plates 1 and 2.

The following water-proofing ingredients were used in the tests: Maumee, Hercules, Medusa, Hydro, McCormick Water-proofing, and Anti-Hydro. All of these except Anti-Hydro are dry white powders which are to be mixed with the dry cement. The manufacturer of each compound recommends that enough of the compound be used to replace 2% of the cement used, and that amount was used in these tests. Anti-Hydro is a liquid which is to be mixed with the water. The manufacturer recommends that 10% of the weight of the water be replaced by this ingredient.

The water-proofing materials are manufactured by the following companies.

Maumee by "The Maumee Chemical Company", Toledo, Ohio.

Hercules by "The Hercules Water-Proof Company", Buffalo, New York.

Medusa by "The Sandusky Portland Cement Company", Sandusky, Ohio.

Hydro by "The Concrete Steel Products Company", Chicago Heights, Illinois.

McCormick Water-Proofing by "The McCormick Portland Cement Company", St. Louis, Mo.

Anti-hydro by "The American Diamond Blast Company", New York, N. Y.

In addition to the above materials two water-proof cements were used in the tests. These are known by the names of Anhydrous Water-Proof Cement and McCormick Water-Proof Cement.

TABLE I.

SIEVE ANALYSIS OF CEMENT

No. of Sieve.	Size of Sieve Opening -inches.	Total Amount of Cement Passing.	
		Units.	Per Cent
20	0.034	1000.0	100
74	0.0078	981.0	98.1
100	0.0045	946.0	94.6
200	0.0027	732.0	73.2

TABLE 2.

SIEVE ANALYSIS OF SAND

No. of Sieve.	Size of Sieve Opening -inches.	Total Amount of Sand Passing.	
		Grams.	Per Cent.
	0.20	1000	100
5	0.160	952.80	95.3
8	0.093	824.20	82.4
10	0.073	699.50	70.0
16	0.042	441.90	44.2
20	0.034	404.65	40.5
30	0.022	253.45	25.3
40	0.015	137.05	13.7
60	0.009	50.40	5.0
74	0.0078	32.95	4.0
100	0.0045	17.15	1.7
150	0.0033	12.45	1.2
200	0.0027	11.20	1.1

TABLE 3

SIEVE ANALYSIS OF STONE

No. of Sieve	Size of Sieve Opening -inches.	Total Amount of Stone Passing.	
		Grams.	Per Cent.
	0.50	1000.0	100.0
	0.45	879.9	88.0
	0.30	251.7	25.2
	0.20	106.3	10.6
5	0.16	48.3	4.8
8	0.093	37.8	3.8
16	0.042	30.7	3.1
30	0.022	27.2	2.7
60	0.009	22.0	2.2
100	0.0045	18.4	1.8
200	0.0027	14.8	1.5

PLATE I.

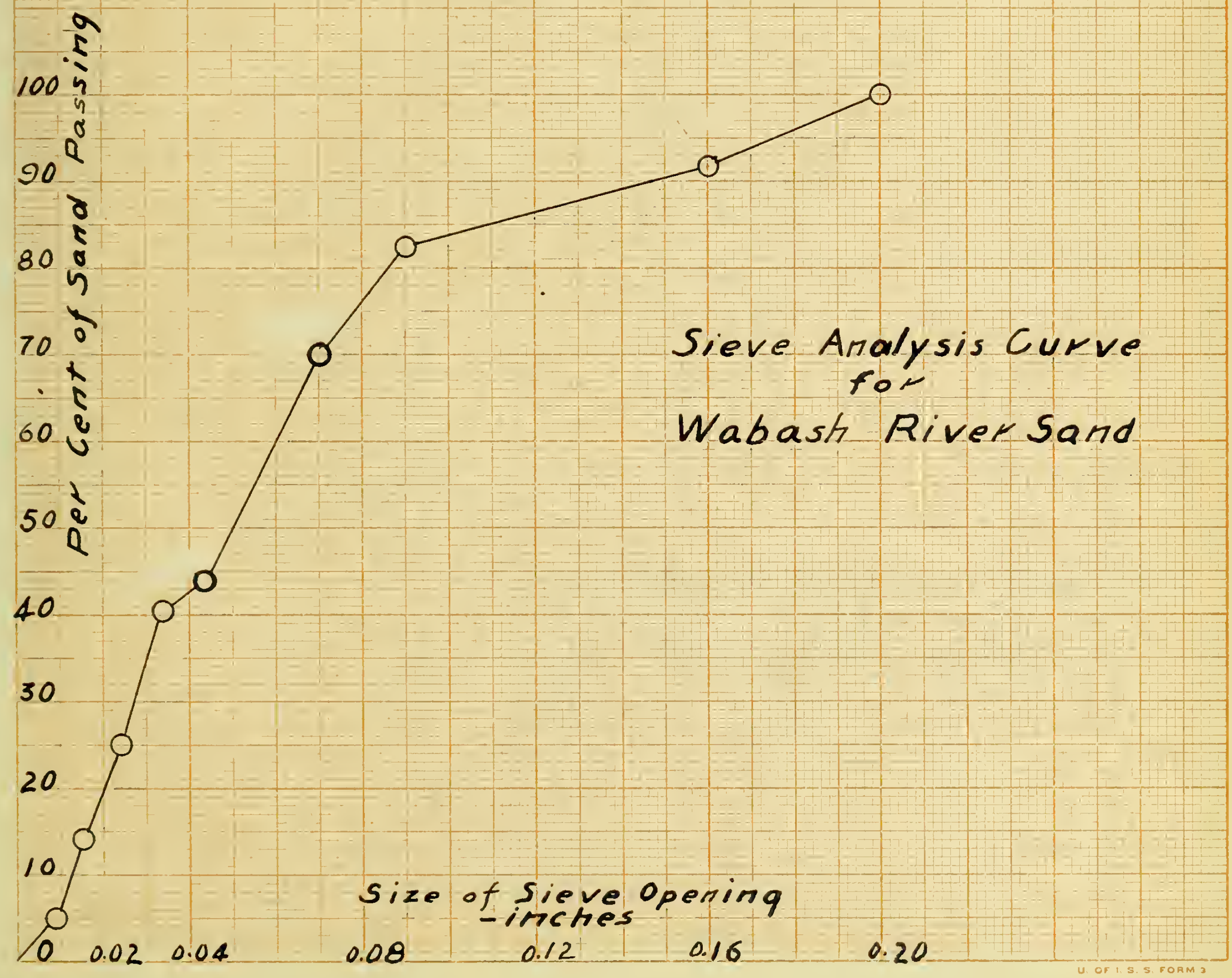
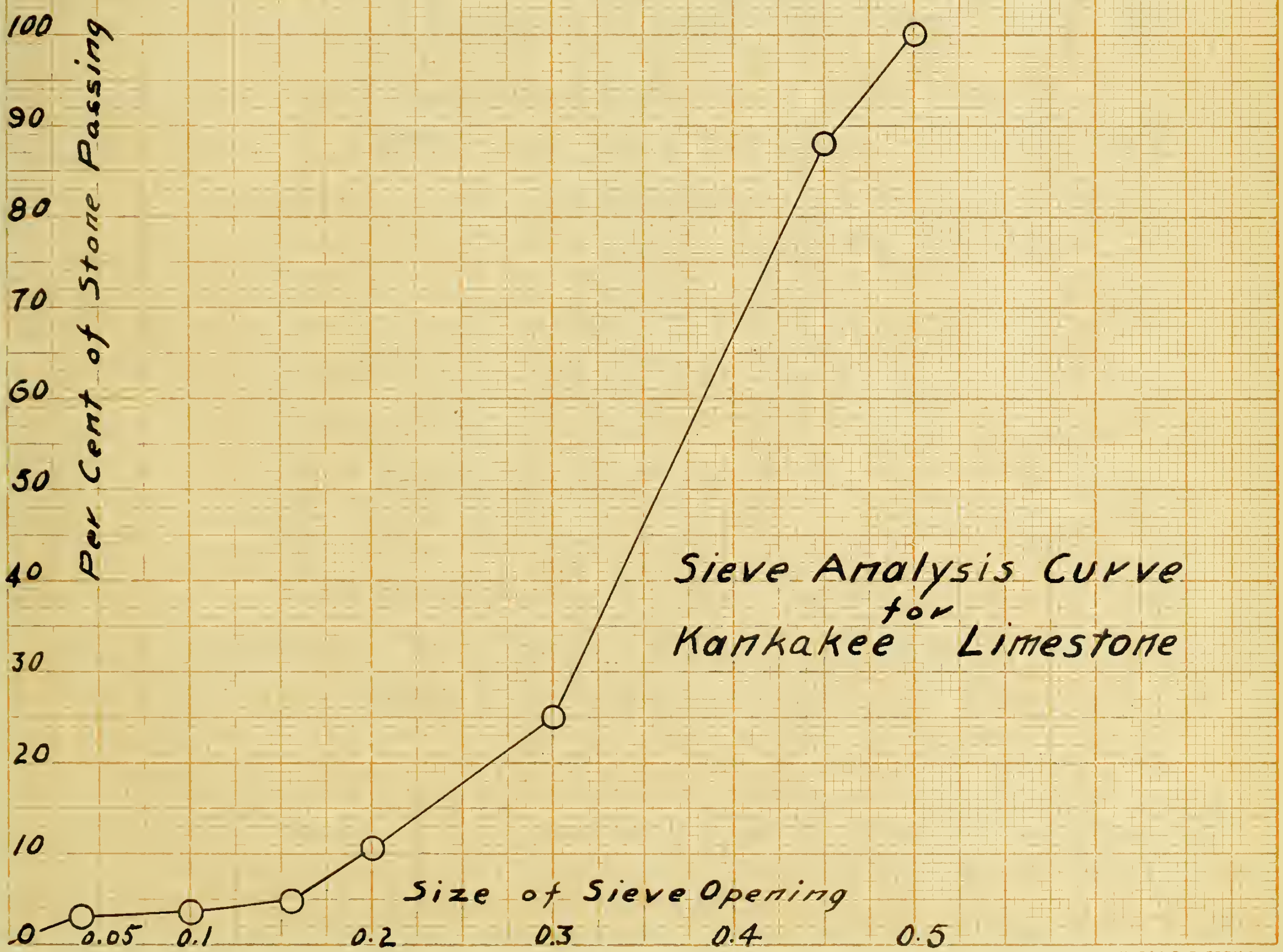

Sieve Analysis Curve
for
Wabash River Sand
Per Cent of Sand Passing
100
90
80
70
60
50
40
30
20
10
0
0.02
0.04
0.08
0.12
0.16
0.20
Size of Sieve Opening
-inches

PLATE 2.

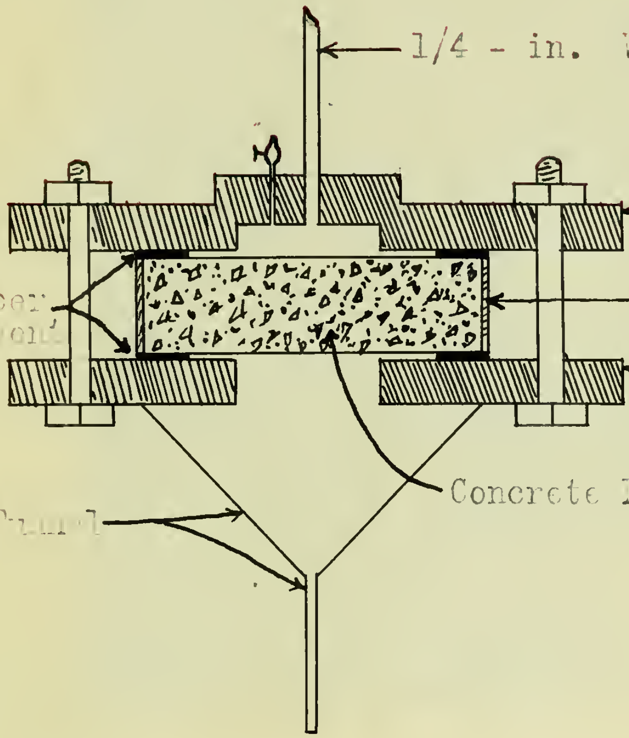


100
90
80
70
60
50
40
30
20
10
0
Per Cent of Stone Passing
0.05
0.1
0.2
0.3
0.4
0.5
Size of Sieve Opening
Sieve Analysis Curve for Kankakee Limestone

2. Apparatus

The apparatus which was used in these experiments, shown in plates 3 and 4, is the same kind as that used by the United States Geological Survey in the laboratory at St. Louis. The apparatus consists of three parts : (I) the top plate, which is of cast iron I in. thick and so arranged that it can be connected with a 1/4 in. water pipe; (2) the bottom plate, which is similar to the top plate and has a 3 - in. opening in the center with a funnel attached beneath it ; (3) the iron ring, which is 7 in. in diameter, 2 in. high, and 1/4 in. thick. The stem of the funnel passes through a rubber cork into the glass flask. The cork prevents evaporation of the water which has percolated through the disc.

PLATE 3



Section through the center

PLATE 4

3. Method

The water-proofing ingredients and cements were tested in both 1:3:6, and 1:2:4 concrete. The proportioning was done by weight, care being taken to have the materials weighed when perfectly dry. No attempt was made to secure a water-proof concrete by means of grading the aggregate. The concrete test pieces were made in the form of discs 7 in. in diameter and 2 in. thick. They were made in the iron rings of the apparatus previously described, and were left in them until after the test was completed. The discs were made and tested in sets, each set consisting of three pairs. One pair was made of clear concrete, and each of the other two pairs was made of concrete which was treated with some water-proofing material.

The materials were thoroughly mixed by hand, and the concrete was then tamped into the rings in layers about three-quarters of an inch thick. The six discs were then stored in damp air for twenty-four hours, after which they were placed in water and left until they were seven days old. At the end of this time they were put into the apparatus and subjected to a constant water pressure due to a static head of 30 ft. In every case the pressure was applied to the surface that was down while the discs were being made. The water which penetrated the discs was caught by the flasks attached to the apparatus, and the amount that came through during each twenty-four hours was weighed and recorded. The test was continued for six days in each case.

IV. RESULTS

The results of these experiments are shown by Tables 4,5, 6 and 7, and the accompanying graphs, Plates 5 and 6 . All the water-proofing materials tested have the effect of decreasing the percolation of water through the discs. The following tables show the relative reduction of percolation of water through the discs in terms of the per cent of that which percolated through the untreated discs.

Relative Reduction of Water Percolating through I:3:6 Concrete Discs

Ref. No.	Water-Proofing Material	Reduction of Total Percolation Per Cent	
		At End of Ist Day	At End of 6 Days
I	None	0	0
2	Medusa	75.6	74.0
3	Anhydrous Water-Proof Cem.	70.0	92.0
4	McCormick Water-Proof Cem.	67.0	57.0
5	Hydro	64.0	52.0
6	Maumee	54.0	60.0
7	Hercules	52.0	45.0
8	McCormick Water-Proofing	20.0	33.0

Relative Reduction of Water Percolating through I:2:4

Concrete Discs

Ref. No.	Water-Proofing Material	Reduction of Total Percolation Per Cent	
		At End of Ist Day	At End of 6 Days
I	None	0	0
2	Medusa	83.0	8I.0
3	Anhydrous Water-Proof Cement	97.0	96.0
4	McCormick Water-Proof Cement	99.6	I00.0
5	Hydro	42.0	6I.5
6	Maumee	30.0	42.0
7	Hercules	64.0	66.5
8	McCormick Water-Proofing	69.0	74.0
9	Anti-Hydro	I00.0	I00.0

TABLE 4

EFFECT OF WATER-PROOFING COMPOUNDS UPON 1:3:6 LIMESTONE CONCRETE.

Ref. No.	Water-Per Cent of Dry Material	Water-proofing	Percolation of Water through 2.0-inch Concrete Dics under a Head of 30 feet grams per 24 hours					
			1st day	2nd day	3rd day	4th day	5th day	6th day
1	9	None	409.1	239.2	171.5	130.5	112.3	90.0
2	9	"	414.6	243.5	180.0	140.8	117.9	93.0
	Mean		411.6	241.3	175.7	135.6	114.6	91.5
3	9	Maumee 2% Of Cement	Cracked while clamping					
4	9	"	314.2	218.2	131.1	92.5	71.9	54.1
5	9	Hercules 2% Of Cement	230.4	188.4	136.5	107.2	79.1	53.7
6	9	"	165.7	129.9	89.0	51.2	46.6	33.7
	Mean		198.1	159.1	112.7	79.2	62.8	43.7
7	9	None	247.7	102.7	66.1	56.4	42.0	35.2
8	9	"	398.7	144.9	95.5	77.3	56.8	45.8
	Mean		323.2	123.8	80.8	66.8	49.4	40.5
9	9	Medusa 2% Of Cement	96.9	47.7	28.4	23.3	15.2	12.2
10	9	"	61.5	33.6	12.5	11.7	6.8	5.3
	Mean		79.2	40.6	20.5	17.5	11.0	8.8
11	9	Anhydrous Cement	34.3	13.2	8.6	6.4	2.7	2.2
12	9	"	14.0	9.1	3.6	2.5	2.1	1.5
	Mean		24.2	11.2	6.1	4.5	2.4	1.9

TABLE 5

EFFECT OF WATER-PROOFING COMPOUNDS UPON I:3:6 LIMESTONE CONCRETE

Ref. No.	Water-Per Cent of Dry Material	Water-proofing	Percolation of Water through 2.0-inch Concrete Dics under a Head of 30 feet grams per 24 hours					
			Ist day	2nd day	3rd day	4th day	5th day	6th day
I	9	None	402.5	174.0	III.4	75.6	54.3	35.0
2	9	"	392.I	165.I	100.2	68.I	41.8	27.2
	Mean		397.3	169.6	105.8	71.9	43.I	31.I
3	9	Hydro 2% Cement	148.I	107.3	64.8	40.2	I7.0	9.I
4	9	"	I39.2	91.2	59.3	31.3	I4.I	7.2
	Mean		I43.7	99.3	62.I	35.8	I5.I	8.2
5	9	Maumee 2% Cement	206.6	94.4	35.0	21.0	I7.6	9.8
6	9	"	I57.6	52.2	28.0	I7.I	I2.5	5.I
	Mean		I82.I	73.3	31.5	19.I	I4.8	7.5
7	9	None	257.3	58.0	22.3	I4.I	9.0	4.2
8	9	"	337.0	I27.I	60.4	38.0	27.5	I3.I
	Mean		279.2	92.I	4I.4	26.I	I8.3	8.2
9	9	McCormick 2% Cement	Cracked while clamping					
IO	9	McCormick Cement	47.2	37.I	I5.I	I2.2	5.8	2.5
II	9	"	I38.3	60.I	41.0	25.I	II.2	5.0
	Mean		92.7	48.6	28.I	I8.7	8.5	3.8
I2	9	McCormick 2% Cement	229.2	44.0	I9.0	I3.2	4.5	2.I

TABLE 6

EFFECT OF WATER-PROOFING COMPOUNDS UPON 1:2:4 LIMESTONE CONCRETE

Ref. No.	Water-Per Cent of Dry Material	Water-proofing	Percolation of Water through 2.0-inch Concrete Dics under a Head of 30 feet grams per 24 hours					
			1st day	2nd day	3rd day	4th day	5th day	6th day
1	10	None	48.1	24.3	12.1	7.2	4.5	3.1
2	10	"	41.9	20.6	10.2	6.3	3.2	2.4
	Mean		45.0	22.5	11.2	6.8	3.9	2.8
3	10	Anti-Hydro 10% of Water	0.0	0.0	0.0	0.0	0.0	0.0
4	10	"	0.0	0.0	0.0	0.0	0.0	0.0
5	10	Hercules 2% of Cement	16.0	8.1	4.0	1.3	0.0	0.0
6	10	"	23.4	11.4	5.3	2.1	1.1	0.0
	Mean		19.7	9.8	4.7	1.7	0.6	0.0
7	10	None	93.6	26.1	13.5	7.1	3.0	1.5
8	10	"	116.2	35.2	20.1	11.4	5.1	2.0
	Mean		104.9	30.7	16.8	9.3	4.1	1.8
9	10	Medusa 2% of Cement	24.4	12.1	4.1	2.1	0.5	0.0
10	10	"	13.4	6.4	2.0	0.5	0.0	0.0
	Mean		18.4	9.3	3.1	1.3	0.3	0.0
11	10	Anhydrous Cement	4.1	2.1	0.0	0.0	0.0	0.0
12	10	"	3.6	0.0	0.0	0.0	0.0	0.0
	Mean		3.8	2.1	0.0	0.0	0.0	0.0

TABLE 7

EFFECT OF WATER- PROOFING COMPOUNDS UPON I:2:4 LIMESTONE CONCRETE

Ref. No.	Water-Per Cent of Dry Material	Water-proofing	Percolation of Water through 2.0-inch Concrete Dics under a Head of 30 feet grams per 24 hours					
			Ist day	2nd day	3rd day	4th day	5th day	6th day
I	IO	None	21.8	15.0	12.1	9.2	4.6	2.1
2	IO	"	38.2	28.0	20.2	15.5	8.7	4.5
	Mean		30.0	21.5	16.2	12.4	6.2	3.3
3	IO	Hydro 2% of Cement	15.4	2.2	1.0	0.0	0.0	0.0
4	IO	"	19.4	9.0	7.3	5.1	0.0	0.0
	Mean		17.4	5.6	[illegible]	2.6	0.0	0.0
5	IO	[illegible] 2% [illegible]	15.1	10.1	2.3	[illegible]	0.0	[illegible]
6	[illegible]	"	[illegible]	[illegible]	[illegible]	8.4	2.2	0.0
	Mean		21.1	15.1	7.5	4.2	I.1	0.0
7	IO	None	50.0	30.1	17.4	8.2	4.1	2.4
8	IO	"	60.3	35.6	20.1	12.4	5.1	3.2
	Mean		55.2	32.9	18.8	10.3	4.6	2.8
9	IO	McCormick 2% of Cement	16.5	7.1	4.1	2.3	0.0	0.0
IO	IO		17.9	8.4	5.3	3.1	1.2	0.0
	Mean		17.2	7.8	4.7	2.7	0.6	0.0
II	IO	McCormick Cement	0.8	0.0	0.0	0.0	0.0	0.0
I2	IO	"	0.0	0.0	0 0	0.0	0.0	0.0
	Mean		0.4	0.0	0.0	0.0	0.0	0.0

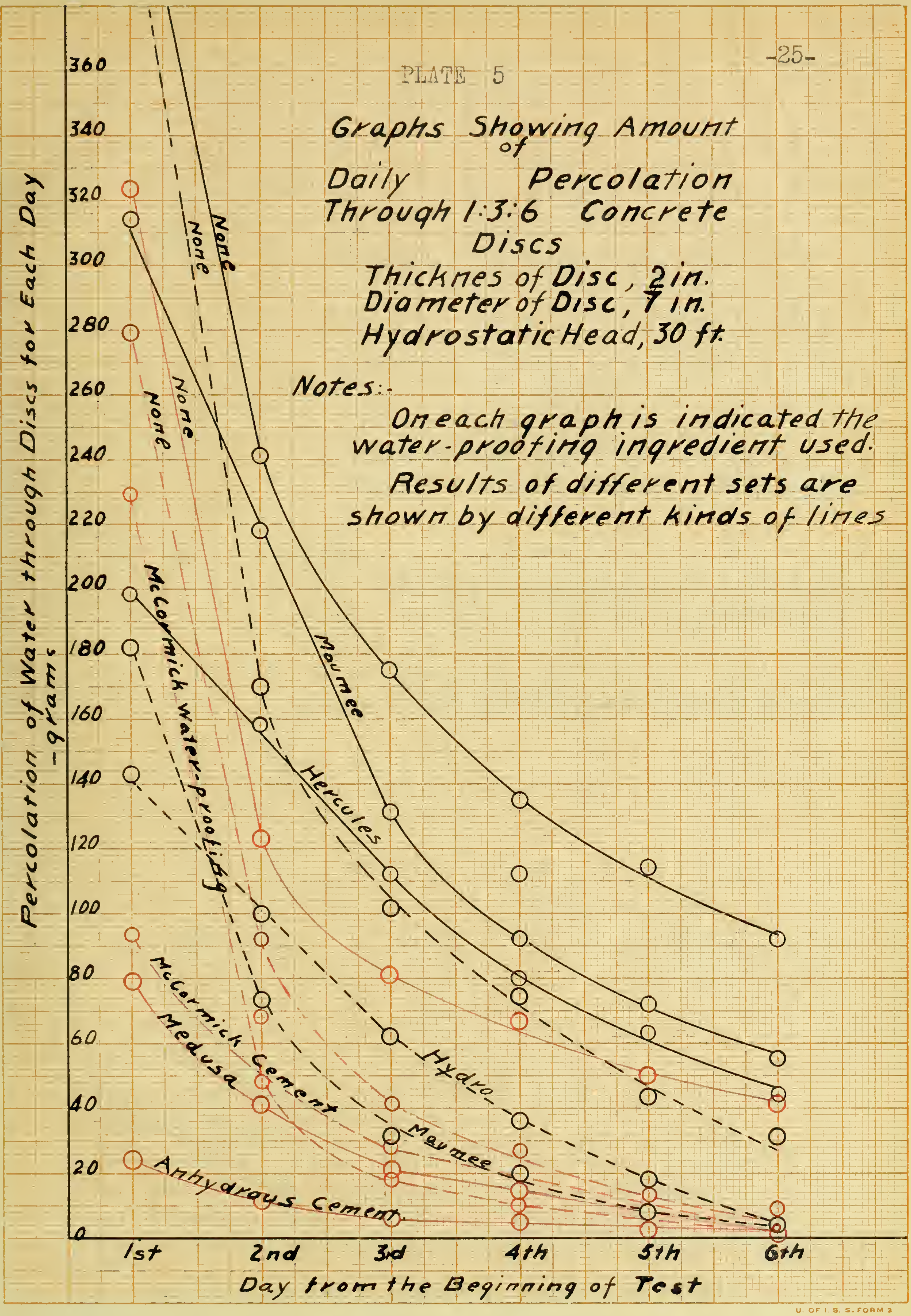
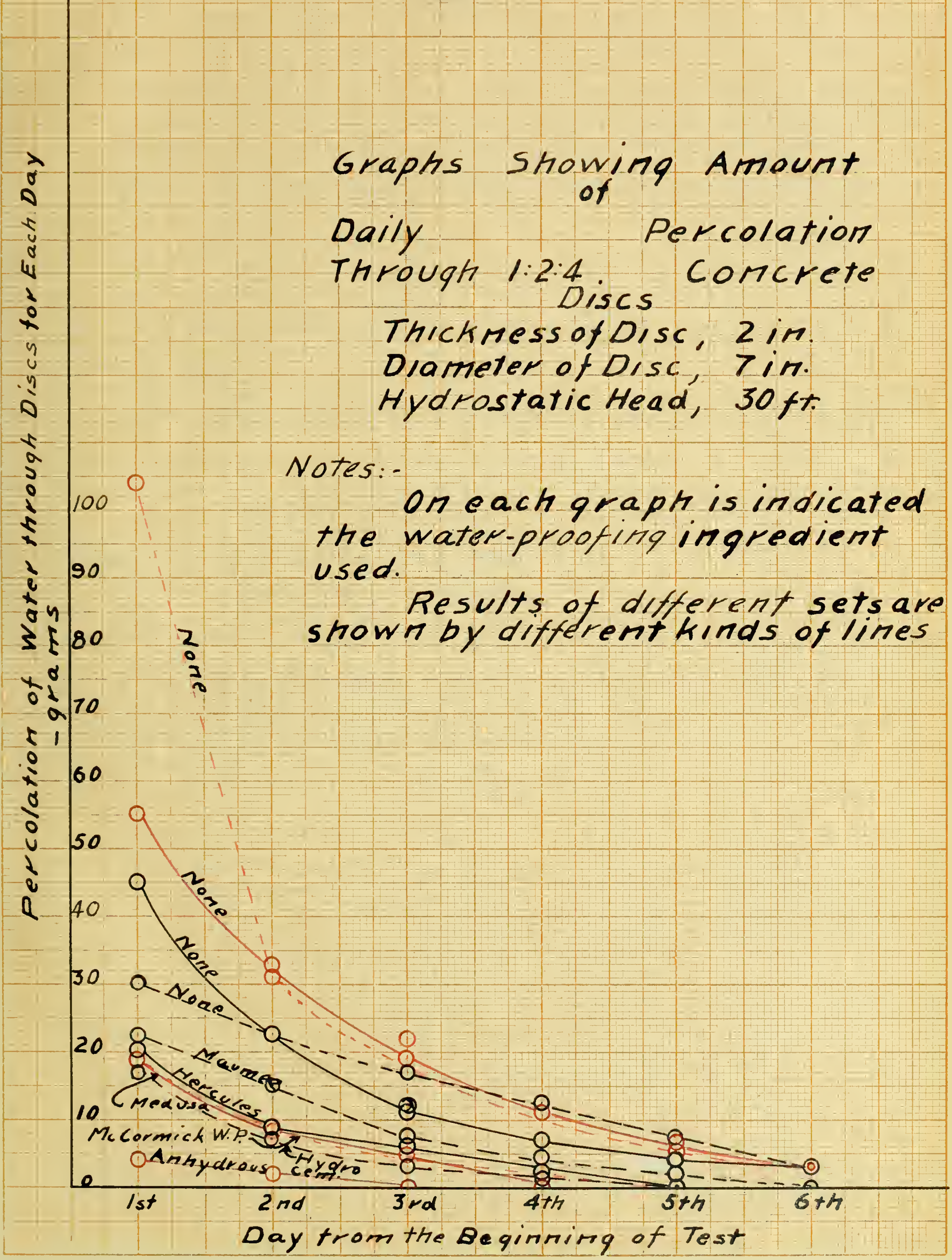


PLATE 5
Graphs Showing Amount of Daily Percolation Through 1:3:6 Concrete Discs
Thicknes of Disc, 2 in.
Diameter of Disc, 7 in.
Hydrostatic Head, 30 ft.
Notes:-
On each graph is indicated the water-proofing ingredient used.
Results of different sets are shown by different kinds of lines
Percolation of Water through Discs for Each Day - grams
Day from the Beginning of Test
1st
2nd
3d
4th
5th
6th
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
None
None
None
None
Moumee
Hercules
McCormick Water-proofing
McCormick Cement
Medusa
Hydro
Moumee
Anhydrous Cement

PLATE 6


Graphs Showing Amount of Daily Percolation Through 1:2:4 Concrete Discs
Thickness of Disc, 2 in.
Diameter of Disc, 7 in.
Hydrostatic Head, 30 ft.
Notes:-
On each graph is indicated the water-proofing ingredient used.
Results of different sets are shown by different kinds of lines
Percolation of Water through Discs for Each Day - grams
0
10
20
30
40
50
60
70
80
90
100
None
None
None
None
Maumee
Hercules
Medusa
McCormick W.P.
Hydro Cem.
Anhydrous
1st
2nd
3rd
4th
5th
6th
Day from the Beginning of Test

V. CONCLUSION

The results of these experiments show that the permeability of concrete can be greatly diminished by the use of water-proofing compounds. The principal conclusions to be drawn from these tests are:-

(1) There is no necessity of using two grades of concrete, as the general effect of the water-proofing material is the same in each case.

(2) There should be more than two discs of like composition, thus making the results more reliable.

(3) It would be better to use a small number of compounds and to test each more completely.

(4) Results would be made more reliable if thicker discs were tested.

(5) A water pressure of at least 40 lbs. per sq. in . would give results more practicable.